Arrowroot (*Maranta arundinacea*), Food, Feed, Fuel, and Fiber Resource[1]

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Arrowroot biomass and processing residues were evaluated as as a feed, fuel and fiber resource. Ensiled aerial biomass and coarse and fine arrowroot processing residues contained 10.8–21.1% crude protein; 11.1–30.2% crude fiber; 3.8–17.0% ash; and an in vitro dry matter digestibility of 38.5–60.3%. Theoretical yields of 0.27 and 1.60 l of methane at standard temperature and pressure per liter of rhizome wash water and starch-settling water were calculated, respectively. Fuel alcohol production potential from yeast-supplemented aerial biomass and coarse residue were identified. Laboratory pulping of coarse residue was performed. The coarse residue has qualities that may be suited to tear-resistant specialty grade papers, such as wrapping paper and bags. The utilization of arrowroot by-products may lead to increased cultivation of this species as a food, feed, fuel and fiber resource. By-product utilization will also reduce environmental pollution presently resulting from direct discharge of unused by-products.

Maranta arundinacea L. (Marantaceae), commonly referred to as arrowroot, is an herbaceous, perennial plant that grows to a height of 0.9–1.5 m (Raymond and Squires, 1959). Arrowroot is cultivated primarily as a source of food starch, which is found in cylindrical rhizomes (Ciacco and D'Appolonia, 1976; Lii and Chang, 1978).

Historically, St. Vincent, West Indies, produced over 98% of the supply of arrowroot starch for the United States, Canada, Britain and Europe (Bolt, 1962); however, production has declined in the past 2 yr (J. W. Duellimore, pers. comm.). The plant is also grown on other islands in the Caribbean, Southeast Asia (Motaldo, 1967), South America, Philippines (Kay, 1973) and India (Maury and Barooah, 1976). Rhizome yields range from 12.5–31 metric tons/ha and rhizome starch yields at the factory are 8–16% in St. Vincent (Kay, 1973).

Processing of arrowroot starch in St. Vincent is performed by a wet milling process. Rhizomes are washed, mechanically crushed to release the starch, and screened to separate coarse and fine fibrous residue from the starch. The starch, which settles by gravity, is resuspended, washed, separated by gravity and air dried in naturally ventilated buildings (Wurzburg, 1952; Lawton, 1956). Coarse and fine residues from the milling process and wash and settling waters are presently unused and discharged directly from the processing plant without treatment.

Although the arrowroot plant is cultivated primarily as a food source, an integrated approach to utilizing plant biomass and factory residues may enhance the economical return from producing arrowroot starch. The objective of this study was to assess alternative uses for the arrowroot processing residues, as well as for the wash and settling waters.

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MATERIALS AND METHODS

Arrowroot-factory processing waters, coarse and fine residues, rhizomes and plant biomass were collected in April 1982 at the Bellevue, St. Vincent, starch-processing factory.

Duplicate samples of stream water entering the factory, wash water leaving the factory and drain water from the starch settling tank were collected in 250 ml screw-cap tubes. The tubes were treated with 2 drops of phenylmercuric acetate as a biological inhibitor, and refrigerated (4°C) within 48 h. Total, volatile and fixed residues, and chemical oxygen demand (COD) were determined by standard procedures (Greenberg et al., 1981). Elemental analyses were determined by a dry ash procedure (Jones, 1977), using an inductively-coupled plasma spectograph. Theoretical methane yield from anaerobically-fermented processing waters were estimated: 1 g COD reduction being equivalent to 0.35 l of methane at standard temperature and pressure (McCarty, 1974).

Fresh samples of coarse and fine processing wastes and immature (<6 mo) fresh-plant biomass (aerial portions, ≤1.0 m in height) were individually ensiled in 0.946-l capacity sealed glass jars fitted with air-tight polypropylene check valves. Fermentations were performed in triplicate using indigenous microorganisms, or indigenous microorganisms supplemented with 3.0 g of distillers active dry yeast (Universal Foods Corporation, Milwaukee, WI), hydrated in approximately 50 ml of water. The ensiled samples were then transported to the laboratory (48 h) and incubated at 30°C for 157 days. Duplicate control samples of similar untreated fractions were mixed with 1.26 g of metabisulfite as a preservative and frozen within 48 h until analyzed.

The presumptive nutritional value of ensiled and control samples were estimated from the proximate analysis (AOAC, 1975). Crude protein was calculated by multiplying total nitrogen by 6.25. In vitro dry matter digestibility (IVDMD) was determined by the procedure of Tilley and Terry (1963). Gross energy content was determined by bomb colorimetry (Anonymous, 1966).

Unensiled and ensiled subsamples were diluted with distilled water 1:1 (wt/wt), acidified with 20.0 ml of 0.6 N H_2SO_4, and incubated (4°C/24 h) in sealed glass flasks. The supernatant obtained after centrifuging at 12,000 × g/15 min was used for determining volatile acids (VFA), nonvolatile acids (NVA) and alcohols by gas chromatography. VFA concentrations were determined by injecting 2.0 μl samples onto 3% carbowax, 20 m/0.5% H_2PO_4 on 60/80 carbopack B (Supelco, Inc., Bellefonte, PA) by the procedure of DiCorcia and Samperi (1974). NVA were esterified and extracted by the procedure of Holdeman and Moore (1973) and injected onto a column of 10% SP-1000/1% H_2PO_4 on 100–200 chromosorb W AW (Supelco). Alcohols were separated on GP 80/100 carbopack C/0.2% carbowax 1500 as prepared by the procedure of DiCorcia and Samperi (1974). All VFA, NVA and alcohols were compared with standard solutions, which were similarly treated.

A fresh composite sample of coarse processing waste was collected, drained, solar dried for 5 h and returned to the laboratory (48 h). The sample was then dried in a forced air oven (75°C/24 h) and evaluated as a raw fiber resource for making writing and tissue papers by procedures of the Technical Association of Pulp and Paper Industry (1970, 1971, 1981) and Aung (1961).

TABLE 1. NUTRIENT CHARACTERISTICS OF UNENSILED AND ENSILED ARROWROOT FRACTIONS.

Source	Treatment	Crude protein (%)	Ether extract (%)	Ash (%)	Crude fiber (%)	Nitrogen free extract (%)	Neutral detergent fiber (%)	Acid detergent fiber (%)	Lignin (%)	Gross energy (cal/g)	IVDMD[e] (%)
Aerial plant	Control	17.48[a]	2.22[a]	13.97[c]	20.68[c]	45.65[a]	60.27[b]	29.15[b]	2.69[c]	3,716.32[b]	56.28[a]
	Ensiled	12.05[b]	1.99[b]	16.19[a]	27.84[b]	41.93[b]	66.54[a]	43.18[a]	7.15[a]	3,723.90[b]	38.87[b]
	Ensiled with yeast	10.79[b]	1.96[b]	14.81[b]	30.23[a]	42.21[b]	67.75[a]	42.40[a]	5.68[b]	3,778.69[a]	38.48[b]
Coarse residue	Control	3.54[c]	0.49[b]	7.43[b]	18.45[c]	70.09[a]	70.99[a]	28.94[c]	3.93[c]	3,587.87[a]	60.25[a]
	Ensiled	3.99[b]	0.68[a]	7.73[a]	20.16[b]	67.44[b]	50.35[c]	33.20[b]	5.16[b]	3,749.98[b]	55.38[b]
	Ensiled with yeast	4.41[a]	0.72[a]	7.89[a]	21.09[a]	65.89[c]	58.93[b]	34.68[a]	5.92[a]	3,740.45[b]	54.70[b]
Fine residue	Control	3.37[c]	0.16[b]	3.77[c]	11.12[c]	81.58[a]	77.75[a]	17.20[c]	2.05[c]	3,545.09[c]	59.40[a]
	Ensiled	4.35[b]	0.55[a]	4.07[b]	15.39[b]	75.64[b]	56.58[b]	26.15[b]	4.07[b]	3,645.65[b]	56.08[b]
	Ensiled with yeast	6.41[a]	0.57[a]	4.95[a]	16.66[a]	71.41[c]	56.41[b]	30.16[a]	6.72[a]	3,792.43[a]	48.13[c]
Corn silage (3-02-822)[d]		7.0	2.8	5.3	25.5	59.3	—	—	—	—	—
Alfalfa silage (3-00-212)[d]		17.3	3.7	8.9	33.1	37.1	52.3	43.2	—	—	—
Sugar beet silage (3-00-662)[d]		12.5	1.9	5.1	32.0	48.5	—	—	—	—	—

[a,b,c] Means from same source followed by the same letter are not significantly different ($P < 0.05$).
[d] International feed number (Ensminger and Olentine, 1978).
[e] IVDMD defined as in vitro dry matter digestibility.

TABLE 2. ACID AND ALCOHOL CONCENTRATIONS IN UNENSILED AND ENSILED ARROWROOT FRACTIONS.

Source	Treatment	Dry matter (%)	Acetic	Propionic	Isobutyric	Butyric	Isovaleric	Valeric	Lactic	Oxalic	Fumaric	Succinic	Methanol	Ethanol
			μ moles/g wet silage											
Aerial plant	Control	17.14	8.25[b]	0.00[c]	0.00[b]	0.00[c]	0.00[b]	0.00[c]	0.00[a]	55.07[a]	2.19[a]	2.19[a]	21.84[a]	3.27[b]
	Ensiled	—	88.11[a]	16.52[b]	4.00[a]	18.75[b]	6.06[a]	2.77[b]	0.00[a]	7.75[c]	3.09[a]	0.86[c]	12.12[a]	4.12[b]
	Yeast	—	119.84[a]	45.33[a]	3.18[a]	30.11[a]	6.19[a]	6.90[a]	0.00[a]	19.98[b]	0.96[a]	1.45[b]	9.40[a]	181.14[a]
Coarse residue	Control	19.06	10.52[c]	0.00[c]	0.00[a]	0.87[b]	0.00[a]	0.00[b]	0.00[c]	10.06[a]	0.00[a]	0.00[c]	33.19[b]	22.69[c]
	Ensiled	17.73	219.14[a]	9.17[b]	0.47[a]	10.36[b]	0.00[a]	0.95[b]	146.30[a]	9.90[a]	0.00[a]	2.56[b]	21.59[b]	86.46[b]
	Yeast	16.86	113.67[b]	22.46[a]	0.00[a]	67.58[a]	0.52[a]	14.23[a]	108.26[b]	7.06[b]	0.00[a]	4.75[a]	96.20[a]	186.97[a]
Fine residue	Control	9.11	6.03[b]	1.67[b]	0.00[a]	0.84[b]	0.00[a]	0.00[c]	0.00[c]	3.61[a]	0.00[a]	0.00[b]	15.15[a]	8.68[a]
	Ensiled	5.90	64.85[a]	32.90[a]	0.63[a]	23.77[a]	0.00[a]	6.37[b]	94.33[b]	2.83[b]	0.00[a]	1.61[a]	22.11[a]	14.14[a]
	Yeast	5.71	62.89[a]	34.14[a]	0.00[a]	22.05[a]	0.00[a]	8.76[a]	115.70[a]	2.35[c]	0.00[a]	1.47[a]	21.72[a]	24.11[a]

[a,b,c] Means from same source followed by the same letter are not significantly different ($P < 0.05$).

TABLE 3. SELECTED MINERAL LEVELS IN UNENSILED AND ENSILED ARROWROOT FRACTIONS.

Source	Treatment	P	K	Ca	Mg	Mn	Fe	B	Cu	Zn	Na
		μg/g									
Aerial plant	Control	1,916.00[b]	36,833.75[c]	4,899.25[c]	3,127.75[b]	43.59[c]	183.88[c]	13.96[b]	7.85[c]	31.86[b]	3,743.25[a]
	Ensiled	2,762.50[a]	49,741.17[a]	6,286.33[b]	4,272.17[a]	79.10[a]	259.87[b]	16.62[a]	11.41[a]	33.34[b]	228.45[c]
	Yeast	2,771.67[a]	42,895.33[b]	6,502.17[a]	4,324.50[a]	72.95[b]	317.88[a]	17.00[a]	10.03[b]	40.56[a]	632.98[b]
Coarse residue	Control	1,242.50[c]	6,104.50[a]	2,032.25[b]	1,780.50[b]	14.16[b]	142.13[b]	5.69[b]	4.90[a]	11.66[c]	1,079.60[c]
	Ensiled	1,478.00[b]	6,938.67[a]	2,672.83[a]	2,172.00[a]	18.17[a]	315.08[a]	6.86[a]	4.48[a]	15.82[b]	407.10[b]
	Yeast	1,687.50[a]	7,117.33[a]	2,736.33[a]	2,218.17[a]	18.54[a]	288.75[a]	7.07[a]	3.92[b]	24.95[a]	451.90[b]
Fine residue	Control	518.63[c]	3,163.75[a]	3,006.25[c]	1,440.50[c]	13.23[b]	124.40[c]	7.73[b]	6.14[c]	13.93[c]	2,454.50[a]
	Ensiled	840.07[b]	4,743.33[a]	4,127.50[b]	1,906.17[b]	18.43[a]	266.33[b]	9.55[a]	9.03[b]	31.08[b]	371.48[b]
	Yeast	1,186.83[a]	5,084.83[a]	4,426.67[a]	2,039.50[a]	18.89[a]	325.05[a]	10.19[a]	9.76[a]	80.33[a]	516.33[b]

[a,b,c] Means from same source followed by the same letter are not significantly different ($P < 0.05$).

TABLE 4. CHARACTERISTICS OF ARROWROOT PROCESSING WATERS.

Component	Stream inlet water	Rhizome wash water	Starch-settling water
COD, mg/l	26.9[c]	771.2[b]	4,572.8[a]
Total residue, mg/l	101.0[c]	803.7[b]	4,695.9[a]
Volatile residue, mg/l	42.8[c]	491.8[b]	3,447.7[a]
Fixed residue, mg/l	58.2[c]	311.9[b]	1,248.2[a]
TKN, μg/ml	0.234[b]	1.294[b]	13.05[a]
NH_4, μg/ml	0.052[b]	0.945[b]	23.500[a]
NO_3, μg/ml	0.399[b]	0.200[b]	2.755[a]
P, μg/g	<0.400[b]	0.415[b]	48.750[a]
K, μg/g	2.65[b]	7.00[b]	422.00[a]
Ca, μg/g	12.450[b]	15.500[a]	10.400[c]
Mg, μg/g	5.700[c]	7.350[b]	48.750[a]
Na, μg/g	11.150[b]	11.800[b]	22.950[a]
Fe, μg/g	0.085[c]	1.440[a]	0.860[b]
Zn, μg/g	0.0275[b]	0.023[b]	0.125[a]
Cu, μg/g	0.025[b]	0.020[b]	0.075[a]
Mn, μg/g	<0.003[b]	0.360[a]	0.090[b]
B, μg/g	0.040[a]	0.040[a]	0.045[a]
Mo, μg/g	<0.020[a]	<0.020[a]	<0.020[a]
Pb, μg/g	<0.300[a]	<0.165[a]	<0.300[a]
Cr, μg/g	<0.020[a]	<0.020[a]	<0.020[a]
Cd, μg/g	<0.030[a]	<0.030[a]	<0.030[a]
Ni, μg/g	<0.100[a]	<0.100[a]	<0.100[a]
Co, μg/g	0.010[a]	0.010[a]	0.010[a]
Al, μg/g	0.225[b]	<0.150[c]	0.245[a]
Sr, μg/g	0.040[a]	0.055[a]	0.045[a]
Ba, μg/g	0.010[a]	0.010[a]	0.010[a]
Bk, μg/g	<0.004[a]	<0.004[a]	<0.004[a]
Cl, μg/g	8.45[b]	10.36[b]	148.00[a]
Methane yield, liter/liter effluent	0.01	0.27	1.60

[a,b,c] Mean comparisons between water source followed by the same letter are not significantly different ($P < 0.05$). Theoretical methane yield estimated by procedure of McCarty (1974). Coarse and fine residues in rhizome wash water removed prior to analysis. COD, TKN, NH_4 and NO_3 defined as chemical oxygen demand, total Kjeldahl nitrogen, ammonium, and nitrate, respectively.

Where appropriate, significant differences in treatment means were determined by Duncan's multiple range test using statistical analysis system procedures of Helwig and Council (1979).

RESULTS

Feed value

The nutrient characteristics of unensiled and ensiled arrowroot fractions are presented in Tables 1, 2, and 3. Similar values for various silages are also included for comparative purposes. All values are reported on a moisture-free basis unless otherwise specified. Crude protein, ether extract, nitrogen-free extract and IVDMD were significantly reduced in ensiled aerial plant biomass when compared to similar control samples. Ensiled aerial plant biomass was, however, significantly greater in crude fiber, ash, neutral detergent fiber (NDF), acid detergent fiber (ADF) and lignin levels. Crude-protein content, ether extract, crude fiber and nitrogen-free extract levels in ensiled and yeast-supplemented ensiled arrowroot

TABLE 5. PULP- AND PAPER-MAKING PROPERTIES OF COARSE ARROWROOT RESIDUES.

Component/characteristics	Coarse residue	Bagasse[j,k]
Ash (%)	7.40	2.0
Pentosan (%)	20.67	30–32
Alcohol-benzene solubility (%)	2.44	–
Klason lignin[a] (%)	6.74	19–21
Klason lignin[b] (%)	12.29	–
NaOH solubility[c] (%)		
1% NaOH	42.85	–
5% NaOH	24.9	–
7% NaOH	35.6	–
9% NaOH	57.8	–
Grammage[d] (g/m^2)	58.57	77.6
Caliper[e] (mm)	0.123	–
Apparent density (g/cm^3)	0.4825	–
Bulk (cm^3/g)	2.09	1.44
Burst index[f] ($Kpa \cdot m^2/g$)	4.76	5.24
Tear index[g] ($mN \cdot m^2/g$)	9.1	5.05
Breaking length (km)	6.304	7.9
Stretch (%)	3.3	–
Folds[h] (1.0 kg)	1,346.0	345
Freeness, Canadian standard	94.0	500
Brightness[i]	34.0	–
Pulp yield (clean material, %)	38.1	55.2

[a] Sample retained on 200 mesh, corrected for ash.
[b] Sample passed through 40 mesh and retained on 60 mesh, corrected for ash.
[c] Cooked at 100°C for 2 h.
[d] Grammage defined as paper weight in g/m^2.
[e] Caliper defined as paper thickness in mm.
[f] Burst index reported in kilopascals·m^2/g.
[g] Tear index reported in millinewtons·m^2/g.
[h] Folds determined on Massachusetts Institute of Technology fold meter.
[i] Brightness determined on Elrepho brightness meter, Carl Zeiss, Inc., West Germany.
[j] Gartside and Langfors, 1981.
[k] FAO, 1952.

fractions were comparable with sugar beet silage, although ash levels were 2.9–3.2 times higher in the arrowroot silages. Comparisons within residue treatments showed that crude protein, ether extract, ash, crude fiber and ADF were significantly greater in ensiled coarse residue compared to the coarse control. Similar results were obtained from fine residue comparisons. Comparisons between sources showed that aerial plant biomass was significantly higher in crude protein, ether extract and ash than coarse and fine residues.

Significant differences in acid concentrations within treatments were detected (Table 2). Acetic, propionic, butyric and lactic acids were the predominately detected acids. As expected, ensiled residues generally contained significantly higher acid levels than control samples.

Selected mineral concentrations in unensiled and ensiled arrowroot fractions are presented in Table 3. Mineral concentration varied with plant material source and treatment; levels in ensiled samples were generally greater than unensiled materials. Mineral concentrations in coarse and fine residues were generally lower than aerial plant biomass.

Fuel value

The potential value of arrowroot factory-processing water wastes as a fuel resource are presented in Table 4. The factory outlet waters were significantly higher in COD, total residue, volatile residue, fixed residue, magnesium and iron levels than stream inlet water. Other elements identified were generally lower in inlet and rhizome wash water when compared to starch-settling water. Calculations of the theoretical methane yield from total COD values indicate that 0.27 and 1.60 l of methane gas at standard temperature and pressure can be produced per liter of rhizome wash water and starch-settling water, respectively. This energy could supplement processing energy requirements at the factory or be used for starch drying.

Alcohol production (Table 2) from yeast-supplemented aerial plant and coarse residue ranged from 190.5–283.2 μ moles/g of wet silage. Overall, alcohol levels varied with sample source; methanol levels were significantly higher in yeast-ensiled coarse residue, when compared with unfermented and ensiled coarse residues. Ethanol levels were significantly higher in all yeast-supplemented substrates except fine residue.

Fiber value

The pulp- and paper-making properties of coarse arrowroot residue are presented in Table 5. Similar values for bagasse have also been included for comparative purposes. Ash content of coarse residue was 3.7 times greater than bagasse, which contributed to a 31% reduction in overall arrowroot pulp yield compared with bagasse.

DISCUSSION

Feed value

Presently, aerial biomass from the arrowroot plant is left in the field at harvest time and the coarse and fine residue fractions are discharged from the factory in the rhizome wash water. These materials have potential value as ensiled animal feeds, fuels and fiber resource.

The in vitro nutrient evaluation of aerial, coarse and fine residues indicated significant differences for the various nutrients measured. The data indicate that the material can be ensiled and preserved for later feeding. The crude protein content of the coarse and fine residues, however, was lower than aerial residue and other silages.

In vivo nutrient availability, palatability, toxicity and intake of various arrowroot fractions are presently unknown; however, in vitro data demonstrated that the control and ensiled aerial biomass potentially contained sufficient total crude protein content for various classes of sheep and growing-finishing steer calves and yearlings (National Academy of Sciences, 1975, 1976).

Ensiled aerial biomass was low (less than 40%) in IVDMD and high in ash content, which greatly reduces its value as a ruminant feedstuff when compared with conventional silage. Additional nutrient supplementation at time of ensiling or feeding would be necessary to improve overall value of the ensiled aerial residue.

Coarse and fine residues were low in crude protein content and would require additional nonprotein nitrogen (NPN) supplementation. The relatively high acid levels in these silages would support the use of NPN to enhance crude protein levels and result in more stable salts of the volatile and nonvolatile fatty acids (Conrad et al., 1969). The high moisture content of coarse and fine residues may warrant additional dewatering of these fractions prior to fermentation.

Fuel value

Processing arrowroot starch by the wet milling process can result in environmental pollution if steps are not taken to utilize the factory effluents. These low residue waste streams represent a potential source of recoverable energy in the form of methane gas. Methane production from waste resources is well documented (Stafford et al., 1980; Wise, 1981), and the use of effluent wastes for methane production has the added benefit of reducing environmental pollution. Tropical climates and high solar insolation levels year-round would further enhance economical methane production. Combustion of methane and use of the thermal energy for starch drying would reduce drying time and improve starch quality. Fermentation of the coarse and fine residues in the wash waters would greatly increase volatile residue and COD levels and result in increased methane production potential.

Alcohol production from yeast-supplemented arrowroot biomass and coarse residue demonstrates the potential for fuel alcohol production. Additional fermentation studies are needed to characterize maximum fuel alcohol yields from arrowroot biomass, residues and processing streams.

Fiber value

The fiber test data of coarse residue indicate arrowroot fiber is comparable to bagasse fiber in the area of burst and tensile strength; however, the tear and fold values are much higher, indicating that starch in the residue may be acting as a binder. The arrowroot fiber resembles short hardwood (*Acer, Castanea*) fibers in length; however, the diameter is much smaller. The data indicate the fiber could be used as a specialty pulp for tear-resistant paper, such as bags and wrapping paper.

The use of arrowroot as a raw material for papermaking will depend mainly on its availability and processing costs. The low pulp yields would necessitate additional cleaning of the residue prior to pulping. In St. Vincent, this would be a relatively economical process due to the large amounts of available fresh surface water.

The importance of arrowroot starch in the United States economy was reported to be doubtful (Wurzburg, 1952). Under present production levels, and limited mechanization, this opinion is still valid. Automated cultivation, harvesting and processing, however, could increase and stabilize supplies in the future. Additional cultivation of this species in other geographic regions may further stabilize supplies and stimulate worldwide demand for arrowroot starch. Production studies are presently underway at this location.

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Book Reviews

Some Common Crop Weeds of West Africa and Their Control. P. J. Terry. 132 pp. illus. United States Agency for International Development, Dakar, Senegal, 1983. Price not given.

"This small book," we are told on page 7 of this deceptively simple, bilingual, 10.2 × 17.7 cm volume, "may bring some enlightenment to many who would otherwise have no access to literature and advice on identification and control of weeds." Much information is provided on forty-five important species. Each species treatment occupies two facing pages, the left with a concise description in French and English of the weed emphasizing features of the root, stem, leaves, inflorescence, fruit, seed, and means of propagation. The right-hand page has a two-part illustration: the upper is a view of the inflorescence in well-reproduced full color, the lower is a line drawing of a leaf and, in most treatments, of a seedling. Following the species descriptions are short (one page or less) sections on "Guide to Weed Control in Crops" with specific recommendations for groundnuts, tree crops, cotton, maize, cassava, millet, rice, and sorghum, and a section on control of the especially difficult weeds *Striga* spp., *Cynodon dactylon, Imperata cylindrica,* and *Cyperus rotundus.* A table listing the weeds included in the book and their susceptibilities to the more widely used herbicides, a short bibliography, a glossary, and an index conclude the work.

This book has been very carefully edited. I could find only a single printing/editing error—a period lacking after an author's name. More important, the botanical information seems flawless.

A usable, practical, attractive book that will be of great benefit in both Francophone and Anglophone Africa.

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The Vascular Plants of Indiana. A Computer Based Checklist. Theodore J. Crovello, Clifton A. Keller, and John T. Kartesz. 136 pp. The American Midland Naturalist and University of Notre Dame Press, Notre Dame, Indiana, 1983. $15.00.

In 1940 Deam published his *Flora of Indiana.* The present checklist is the only one of the vascular plants of that state since then. Indiana's flora is now known to consist of 2,265 species, 761 genera, and 150 families. The checklist is just that: a list of names, without synonymy, considered to be the correct ones, with each name preceded by its nameber. Arrangement is alphabetical by family, genus, and species. Following the checklist are a section of "Taxon names in Deam (1940) which have undergone nomenclatural changes or been reduced to synonymy or which Deam had given the incorrect author"; a listing of vascular plant families reported from Indiana, with the number of genera and species of each in the state and in North America; and an index to familial and generic names.

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